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Influence of Closure on the White Water Dissolved Solids and the Physical Properties of Recycled Linerboard

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INFLUENCE OF CLOSURE ON THE WHITE WATER DISSOLVED SOLIDS AND THE PHYSICAL PROPERTIES OF RECYCLED LINERBOARD

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ABSTRACT

The effect of closing the white water system on the physical properties of linerboard produced from recycled fiber under acid rosin sizing conditions was investigated. The closing of the system was simulated in a Formette Dynamique and with a British handsheet mold. The tensile index showed a decrease for the British handsheet mold handsheets as the white water system was closed and water recycling was simulated. Zero span tensile strength, ring crush, tear, and sizing were not affected significantly. Inorganic materials showed an increase in concentration in the white water with closure and recycling. Therefore, at high levels of closure (above about 70%), the continuous addition of alum in this papermaking system should be limited to the aluminum ion adsorption capacity of the fiber. However, inorganic buildup cannot be avoided for sodium, calcium, chloride, and sulfate because they are not removed well with the fiber, but are continuously added with the stock, starch, rosin, and alum. No steady state was reached for these inorganics at high closure levels. Therefore, precipitation may eventually occur (likely involving low solubility elements such as calcium), and interference with the physical chemistry of the papermaking system can be expected.

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INTRODUCTION

The consumption of secondary fiber has increased considerably over time. On average, one third of the world's fiber needs for paper production are supplied by recycling (1). One of the largest secondary fiber consumers is the packaging sector, where mills that produce recycled linerboard and corrugated medium play an important role.

In the last 20 years, great efforts have been made to reduce water pollution by paper mills (2). One way to achieve this is to install effluent treatment, which requires significant capital investment. Another approach is to close the white water system of the mill. Mills must then reuse the water that was previously going from the paper machine to effluent treatment. In this way, points where fresh water is consumed, such as wire showers, felt showers, roll showers, water gland seals, and dilution points in the stock preparation system, are changed to use white water (3). Most of the time, the white water is cleaned of suspended particles by passing it through a saveall or clarification system. The dissolved material, however, is almost completely recycled to the paper machine.

Thus, three factors control the extent to which white water recycling can be practiced (4): thermal energy buildup, suspended solids buildup, and dissolved solids buildup.

The temperature increase in the white water is due to the reduction in heat when less cool fresh water is used, and less warm white water is discharged (5). This temperature rise often results in more benefits than problems. It improves the drainage rate of the web in the forming sections and in the press section. Because of the great amount of heat transfer area, such as pipes and reservoir surfaces, the temperature of the white water system reaches a new equilibrium point and stabilizes, often without further problems.

Paper-machine white water, whether it is recycled or not, contains a variety of soluble salts and organic materials. Some of these are introduced via the freshwater supply, although the majority originate from the pulp or wastepaper used, or are chemicals deliberately added to the system (6).

The water in a paper-machine system therefore contains a variety of dissolved materials. The main species are: hemicelluloses, lignin derivatives, starches, sizing agents, defoamers, dyes, surfactants, slimicides, and synthetic polymers. This list is not comprehensive, and the dissolved materials will vary greatly in concentration and in the species present from machine to machine (6). However, with increased closure of water systems, there will be an increasing amount of dissolved substances in the white water (6). The net effects of closure on process water are increases in ionic concentration, concentration of dissolved organic substances, temperature, and levels of suspended solids (fines/fillers) (6), (7), (2).

The increase of ionic concentration may influence the strength properties of the resultant paper (6), adsorption of additives, the mechanisms of retention, the total acidity/aluminum ion concentration, sizing; the microbiological environment; and corrosion.

Reported effects of system closure (8) show that positive and negative effects have been observed when the white water system of a paper mill is closed. Each mill situation has to be considered as a unique case, and the effect of closing the white water system in a particular mill cannot be applied directly to other mills.

OBJECTIVES

We have investigated the effect of the dissolved materials on the physical properties of recycled linerboard when white water system closure is implemented. The objectives were:

1. To determine the increase of organic and inorganic dissolved solids in a white water system for producing recycled linerboard under acid sizing at different degrees of closure. The behavior of pH, inorganics, and total organic carbon was investigated.
2. To determine how much the physical properties of this linerboard are affected by the increase of dissolved solids at different levels of white water system closure. Tensile, ring crush, tear, zero tensile span, and cobb number were monitored.

EXPERIMENTAL

Level of Closure and Stock Used

The level of closure for each handsheet formed was defined as

$$LC = (V_{ww} / (V_{fw} + V_{ww}))*100 \qquad (1)$$

where LC is the level of closure in %; V_{ww} is the volume of white water; and V_{fw} is the volume of fresh water, both in liters (L). The research simulated the closing of a white water system to produce linerboard (205 g/m^2) from recycled fiber. The stock is described below.

Formette Dynamique Handsheets

Recycling was simulated by forming handsheets in the Formette Dynamique and reusing the white water for the next handsheet. This was repeated six times for each level of closure. During the recycling of the white water, the levels of organic and inorganic dissolved solids were determined in each cycle. Conductivity and pH were monitored.

The levels of closure LC (eq. 1) of the white water system for the Formette handsheets were 73, 87, and 100%.

Chemical addition

The chemicals were added to the furnish in the same amounts that they are used in a typical recycling mill (40 kg aluminum sulfate/oven dry ton of fiber (odt), 12 kg cationic starch/odt, 6 kg rosin soap/odt). The water used to prepare the chemicals was deionized water. Chemicals were added for each new handsheet. The first handsheet was formed without chemical addition to determine the properties of the stock.

Stock, stock preparation, and handsheet formation

The fiber was received from a 100% recycled linerboard paper mill that uses 80% old corrugated container (OCC), 10% sack paper, and 10% boxboard. The stock in this mill is cleaned by pulping, high density cleaners, coarse screening, forward cleaners, reverse cleaners, thickening, and fractionation. The long fiber fraction of the stock had 3.54% consistency and a freeness of 450 CSF; the short fiber fraction had a 3.64% consistency and a freeness of 385 CSF.

The procedure to produce the handsheets of a basic weight of 205 g/m^2 in the Formette Dynamique was:

1. A suspension of 0.2% consistency (11 liters) containing 22 g o.d. long fiber, and a suspension of 0.2% consistency (7 liters) containing 7 g o.d. fiber were prepared. One liter of each suspension was taken for analysis. The water used to form the water seal in the Formette Dynamique was tap water. (municipal water, 21.5 mg/liter hardness as $CaCO_3$)
2. First the rosin soap was added, second the aluminum sulfate, and finally the cationic starch (5 minutes between the additions).

3. The handsheets were formed by adding first 5 liters of long fiber suspension, then 6 liters of short fiber suspension, and finally the last 5 liters of long fiber suspension. The drainage of the Formette Dynamique was collected to be used for the formation of the next handsheet. One liter of white water was taken for analysis after each handsheet formation.
4. The first handsheet (start run) was always made without chemical addition and with distilled water to evaluate the as-received properties of the stock.
5. For the 73% level of closure, 16 liters of stock were fed into the Formette Dynamique for the production of each of the seven handsheets. Six liters of fresh water entered the Formette Dynamique for the water seal ring of the wire. The average total drainage was 22 liters per handsheet (level of closure LC was 73 %).
6. Similarly during the 87% closure run 3.5, liters of white water plus 3 liters of fresh water were used to form the water seal ring in the Formette Dynamique. During the 100% totally closed run, 6.5 liters of white water were used to form the water seal ring.

British Mold Handsheets

To check results obtained from the Formette Dynamique, recycling was also simulated using standard 3-gram British mold handsheets (150 g/m^2, TAPPI Standard T 205). Here, the first handsheet was produced without chemicals, then the following 15 recycles were performed with rosin soap and aluminum sulfate addition at the same level that was used for the Formette Dynamique. Two levels of closure were used (70 and 100%). For the 70% level of closure, 70% of the white water from the previous recycle was used for the next handsheet, and the remaining 30% was fresh water. For the 100% level of closure, all the white water from the previous recycle was used for the next handsheet. The fiber used was the same long fiber as for the Formette Dynamique.

RESULTS AND DISCUSSION

The Formette Dynamique handsheets and British mold handsheets were evaluated for ring crush, tear, tensile, zero tensile span, and cobb number. The measurements were made at standard conditions and following TAPPI procedures (TAPPI T 494 for tensile, TAPPI T 822 for ring crush, TAPPI T 414 for tear, and TAPPI T 441 for sizing). Each property measurement was indexed dividing by the basic weight of the handsheet to compare results from different recycles.

The white water drainage after each handsheet formation was evaluated for pH and conductivity. Aluminum, sulfur, and sodium were determined by Inductively Coupled Plasma Emission Spectroscopy (ICP). Dissolved chloride was determined by Capillary Ion Electrophoresis (CEI). The organic white water concentration was monitored after each recycle with the total organic carbon test (TOC).

Mechanical and Physical Properties of Handsheets

The evaluation of the tensile index for the Formette Dynamique handsheets at 73, 87, and 100% closure showed that this property was not affected significantly as the number of recycles increased (Figure 1). The same property for the British mold handsheets showed a slight decrease in tensile index as the number of recycles increased (Figure 2). A possible explanation is that the tensile index for the Formette Dynamique handsheets leveled off due to the successive starch additions. The tensile index represents the fiber to fiber bond, and the successive addition of starch continues to strengthen this bond to a similar level for each handsheet (9). On the other hand, in the British mold handsheets, there was no starch addition. For the British mold handsheets, the increasing concentration of ions in the white water during recycling (see below) reduced the swelling capacity of the fibers, which in turn is known to reduce the relative strength of the bonds between fibers (8). This is detected as a decrease in the tensile index. In summary, the tensile index is at most slightly decreased through white water recycling.

The zero span tensile strength index for both types of handsheets and for different levels of closure showed no change. The zero span tensile strength measures mainly the individual fiber strength rather than the fiber bond strength (10). The recycling of water is not expected to affect the strength of individual fibers.

Other properties such as tear and ring crush do not show any significant change, which would indicate a deterioration of these properties as the number of recycles and the level of closure increased for the Formette Dynamique and the British mold handsheets. Tear is a property that depends on fiber characteristics such as length and coarseness, which are not affected by closing of the water system (11). Ring crush not only depends on fiber to fiber bond strength, but also on structural characteristics of the paper such as the thickness and rush/drag ratio (12). These characteristics are not directly affected by the increased presence of dissolved solids during formation of the sheet.

The sizing of the paper (cobb number) was not affected by increasing the number of recycles and by increasing the level of closure. The sizing value was fairly constant at 20-25 g water/m^2 from recycle 1 to 6 for Formette Dynamique handsheets.

Dissolved Inorganic and Organic Material in the White Water.

<u>Formette Dynamique handsheets</u>

The pH range during the production of Formette Dynamique handsheets with addition of aluminum sulfate (recycle 1 to 6) was from 4.5 to 4.9. In this range of pH, aluminum sulfate dissociates, and the predominant species is Al^{+3}. Having the aluminum in the form of Al^{+3} explains the fairly constant value of the cobb number, because at this pH range, the alum resinate precipitate can form and produce good size retention (14).

Figure 3 shows a steady increase of the aluminum concentration in the white water. The aluminum content of the final paper is approximately constant after recycle 1 (Figure 4). The start run shows the aluminum content coming in with the fiber before the addition of any chemicals. When aluminum sulfate is successively added to the fiber in recycle 1 through 6, the fiber will adsorb a limited amount of aluminum, here about 4500 to 4700 mg aluminum/kg of paper. This matches values from the literature fairly well (13). The additional aluminum, which is coming in with the added aluminum sulfate and with the recycle water, remains in the white water. This steadily increases the white water aluminum content, with the sharpest rise at the highest level of closure.

The increase of sulfur (Table 2) in the white water is due to the successive additions of aluminum sulfate. Some sulfate will go to the fiber with the alum rosin precipitate (15). However, it is clear from Figure 5 that the increase of sulfur in the white water proceeds more rapidly than the increase of aluminum because aluminum is purged much more efficiently with the sheet. This is also evident from the difference between the aluminum content of the sheet from the start run versus the sheet of recycle 1 at 100% recycle (Table 1) because this difference equals roughly the purge capacity of each sheet.

Sodium ions dissociate from rosin soap when added to the pulp suspension. Some ions will attach to the fiber, but most will stay in solution. Table 1 shows a higher content of sodium for the incoming fiber compared to recycle 1. After the start run, there is a drop in the content of sodium in the final paper from recycle 1 to 6 (about 230 to 270 mg sodium/kg of paper). This drop in the sodium content in the final paper is probably due to aluminum ions displacing sodium ions from the fiber due to their higher charge density

(6). Therefore, the fibers will adsorb a reduced amount of sodium ions. The remaining sodium ions coming in with new rosin soap and the recycle water will increase the sodium content of the white water as the number of recycles and level of closure increase (see Table 2).

The chloride in the white water stems mainly from the dissociation of chloride from the cationic substitution groups in the starch. The chloride content in the white water also shows an increase as the closure increases and the number of recycles increases (Table 2). A limited amount of chloride anions is adsorbed on the fiber as shown in Table 1, and additional chloride coming in with the starch will build up in the white water (Table 2).

Calcium comes in with the fiber, fillers in the paper, and with residual calcium in the recycled paper (cement bags in the recycle stream for this mill). The white water content of calcium for 73% LC for Formette Dynamique handsheets levels off at 40 to 44 mg/L after recycle 4. For the 87 and 100% LC, the calcium content in the white water increased steadily (Figure 6). The buildup of calcium content in the white water can be rationalized because fibers will adsorb aluminum cations preferentially over calcium ions (14).

The concentration of organics measured as the Total Organic Carbon (TOC) in the Formette Dynamique white water was relatively constant for the 73% level of closure, but it shows an increase for the 87 and 100% level of closure as the number of recycles increases (Table 2). The TOC is associated with colloidal and soluble materials (starch and rosin) in the white water, fibers, and fiber fines. As the level of recycling increases, the TOC rises. Some scatter in the data may stem from particulate matter (fines).

British mold handsheets

The content of aluminum, sulfur, and sodium in the white water of the British mold handsheets for the 100% level of closure increased steadily with recycling. The absolute concentrations are lower than for the Formette handsheets because the consistency was lower for British mold handsheets. For the 70% level of closure, the content of aluminum, sulfur, and sodium in the white water reaches an approximately constant value as the number of recycles increases. The aluminum content is shown as an example in Figure 7. At 70% closure, the system still has a relatively large purge of the white water. This allows the system to reach a steady state with an equilibrium between addition, purge with water, and purge with the sheet.

Because starch and the associated chloride were not added to the British mold handsheets, the chloride content in the white water was approximately constant through the 15 recycles for the 70 and 100% level of closure.

CONCLUSIONS

This particular recycle fiber and papermaking system reaches a maximum adsorption capacity of aluminum, sulfur, sodium, and chloride on the fibers when the handsheets are formed, as shown in Table 1. This means that the sheet quickly reaches the limit as a "purge" for inorganics and any further addition will lead to a buildup in the white water.

Correspondingly, the results show a steady increase in the content of dissolved inorganic species in the white water as the level of closure and number of recycles increase. Inorganics are introduced deliberately (aluminum) with other added chemicals (chloride with cationic starch, sodium with rosin, sulfate with alum) or with the stock (calcium). Minimizing the addition of chemicals can solve the buildup problem only for aluminum, since purge (with the fiber) and controlled addition can potentially be balanced. Other inorganics that do not associate strongly with the fiber will steadily build up at high closure levels. This cannot be avoided because starch and rosin have to be added to the system continuously to maintain strength and sizing, but virtually only the organic part of these materials leaves with the sheet.

The sizing and the physical properties (ring crush, tear, and zero tensile span) appeared not to be significantly affected as the white water system was closed and the number of recycles increased. Only a slight decrease in the tensile index of the British mold handsheets was found, due to the absence of starch additions.

At high closure levels (70-75% and above), a buildup of dissolved inorganics and organics occurs, without any sign of reaching equilibrium at 100% closure during the number of recycles tested here. The aluminum buildup could probably be controlled by balancing addition and purge with the sheet. This is not possible for other inorganics introduced with starch, rosin, and the recycle stock. Ions with low solubility, such as calcium, can then cause precipitation problems, if the sheet properties do not first deteriorate to unacceptable levels as high ionic strengths are reached. For a tightly closed system, a selective purge for dissolved inorganics from the white water is clearly needed.

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LIST OF FIGURES.

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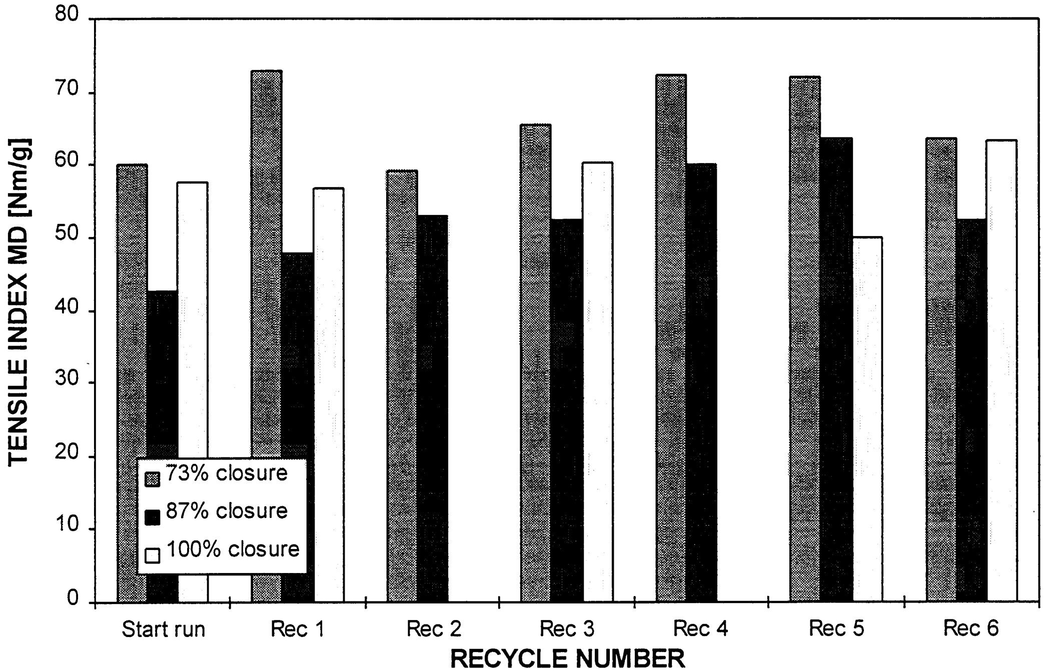
		Aluminum in paper mg/kg	Sulfur in paper mg/kg	Sodium in paper mg/kg	Chloride in paper mg/kg
Start run		3080.0	1102.0	357.0	74.3
Recycle	1	4850.0	1310.0	266.0	68.6
	2	4570.0	1300.0	240.0	68.4
73%	3	4530.0	1300.0	259.0	63.6
of	4	4710.0	1370.0	248.0	75.0
closure	5	4480.0	1330.0	243.0	66.5
	6	4580.0	1370.0	267.0	86.2
Start run		2950.0	1060.0	333.0	68.7
Recycle	1	4980.0	1320.0	246.0	70.6
	2	4550.0	1280.0	239.0	46.8
87%	3	4410.0	1310.0	260.0	55.5
of	4	4700.0	1380.0	241.0	61.1
closure	5	4450.0	1360.0	248.0	44.2
	6	4500.0	1370.0	263.0	63.1
Start run		2990.0	1090.0	286.0	58.1
Recycle	1	5100.0	1370.0	230.0	50.5
	2	4500.0	1360.0	237.0	53.0
100%	3	4720.0	1410.0	236.0	53.8
of	4	4550.0	1400.0	245.0	55.4
closure	5	4540.0	1430.0	250.0	59.6
	6	4622.0	1460.0	248.0	92.0

Table 1

		Aluminum in water mg/L	Sulfur in water mg/L	Sodium in water mg/L	Chloride in water mg/L	TOC in water mg/L
Start run		0.11	7.70	3.80	1.00	106
Recycle	1	4.00	27.00	7.70	2.10	78
	2	7.10	38.00	10.00	3.10	71.5
73%	3	9.40	47.00	13.00	3.80	112
of	4	11.00	52.00	14.00	4.30	118
closure	5	12.00	59.00	15.00	4.70	97.5
	6	13.00	58.00	16.00	5.10	99
Start run		0.11	6.90	3.60	0.60	52.5
Recycle	1	2.00	23.00	7.70	2.60	64.5
	2	3.00	25.00	7.90	2.60	44.5
87%	3	8.00	54.00	15.00	4.40	116.5
of	4	11.00	62.00	17.00	4.60	95
closure	5	15.00	75.00	20.00	5.20	130.5
	6	17.00	78.00	20.00	5.80	188
Start run		0.18	7.53	4.10	0.80	39.5
Recycle	1	4.11	25.60	8.11	3.10	
	2					
100%	3	15.70	62.30	16.10	5.40	94
of	4					
closure	5	24.30	93.20	23.80	8.60	142.5
	6	28.80	108.00	27.20	7.50	213

Table 2



TENSILE INDEX MD [Nm/g]
80
70
60
50
40
30
20
10
0
73% closure
87% closure
100% closure
Start run
Rec 1
Rec 2
Rec 3
Rec 4
Rec 5
Rec 6
RECYCLE NUMBER

Figure 1

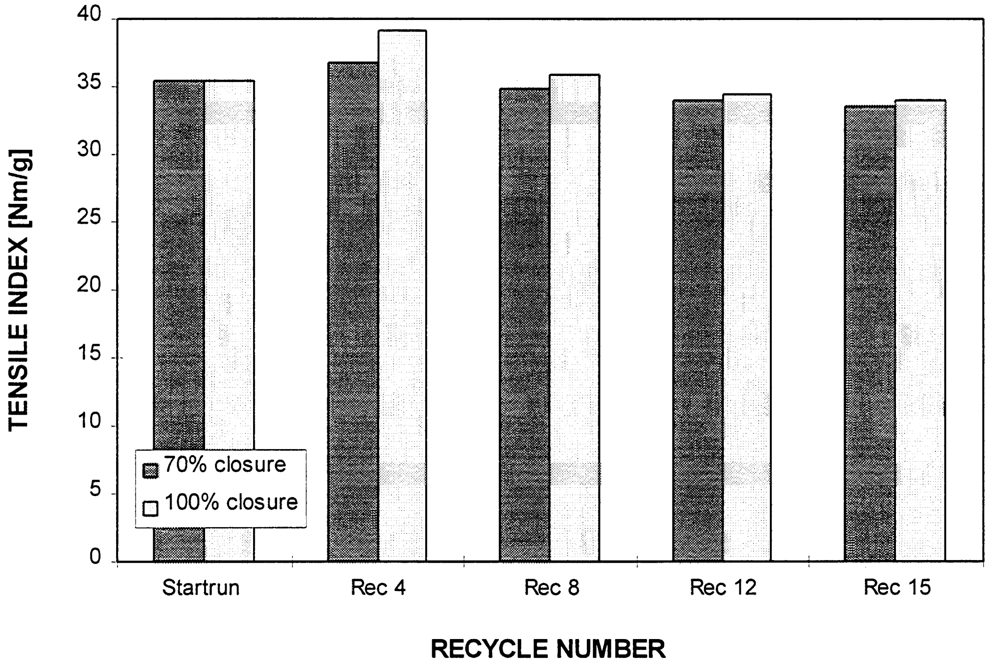
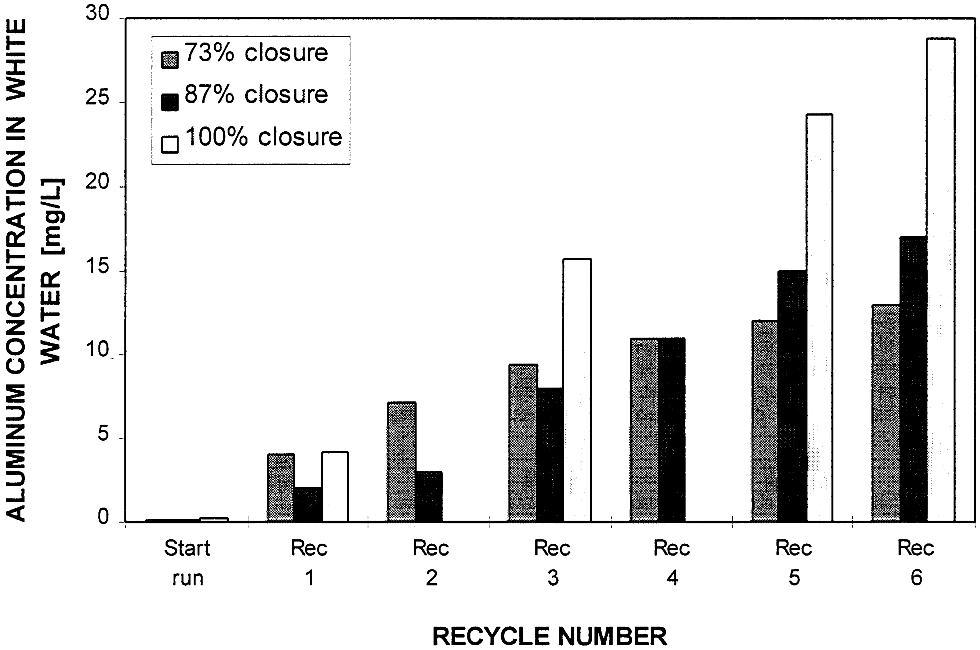

40
35
30
25
20
15
10
5
0
TENSILE INDEX [Nm/g]
70% closure
100% closure
Startrun
Rec 4
Rec 8
Rec 12
Rec 15
RECYCLE NUMBER

Figure 2



ALUMINUM CONCENTRATION IN WHITE WATER [mg/L]
30
25
20
15
10
5
0
73% closure
87% closure
100% closure
Start run
Rec 1
Rec 2
Rec 3
Rec 4
Rec 5
Rec 6
RECYCLE NUMBER

Figure 3

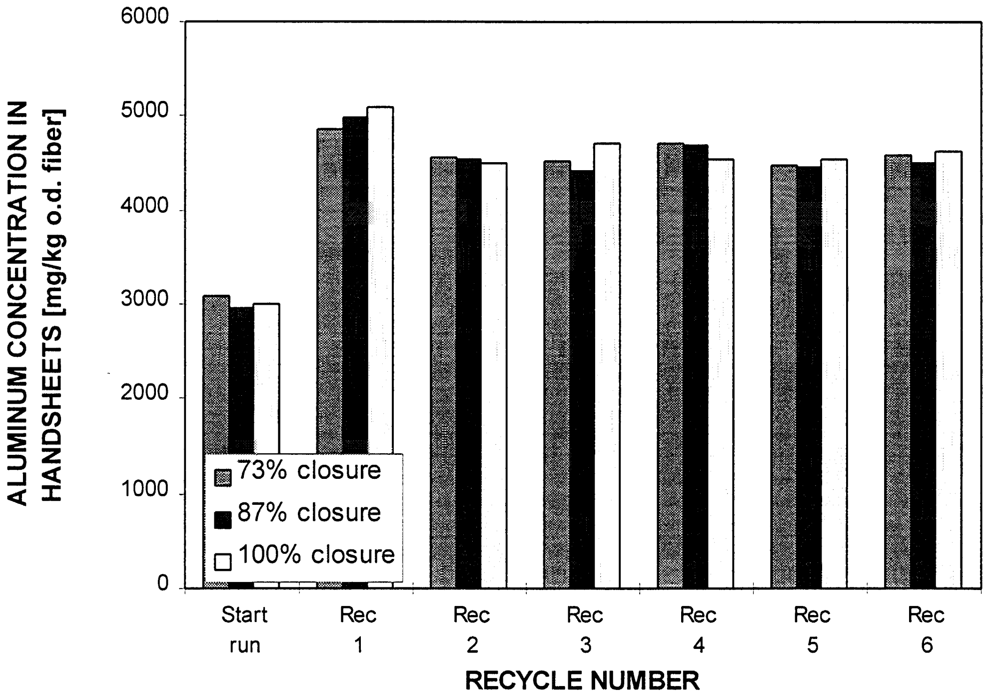

6000
5000
4000
3000
2000
1000
0
ALUMINUM CONCENTRATION IN HANDSHEETS [mg/kg o.d. fiber]
73% closure
87% closure
100% closure
Start run
Rec 1
Rec 2
Rec 3
Rec 4
Rec 5
Rec 6
RECYCLE NUMBER

Figure 4

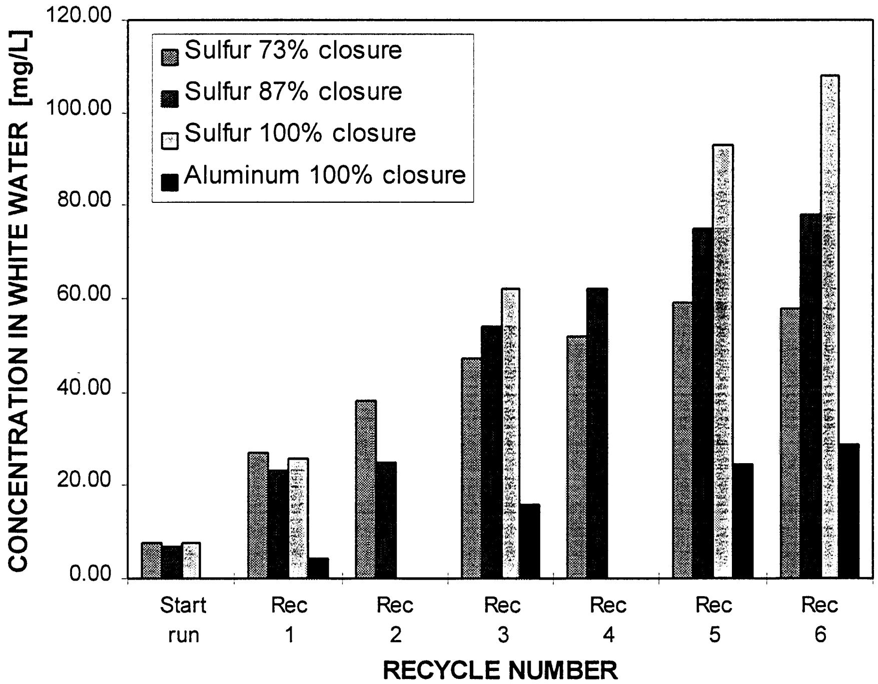
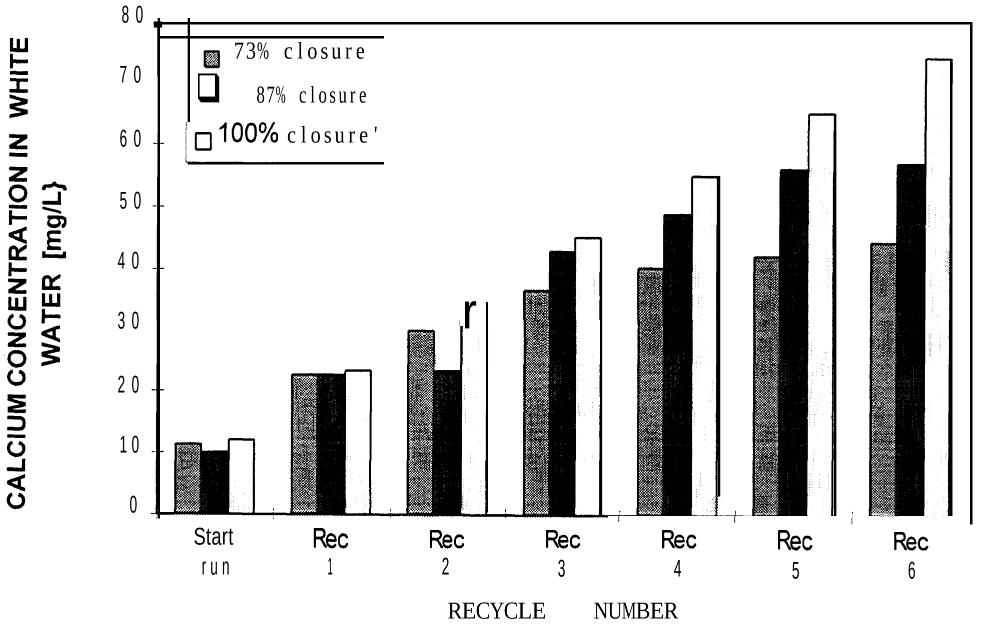

CONCENTRATION IN WHITE WATER [mg/L]
120.00
100.00
80.00
60.00
40.00
20.00
0.00
Sulfur 73% closure
Sulfur 87% closure
Sulfur 100% closure
Aluminum 100% closure
Start run
Rec 1
Rec 2
Rec 3
Rec 4
Rec 5
Rec 6
RECYCLE NUMBER

Figure 5



CALCIUM CONCENTRATION IN WHITE WATER [mg/L}
80
70
60
50
40
30
20
10
0
73% closure
87% closure
100% closure'
Start run
Rec 1
Rec 2
Rec 3
Rec 4
Rec 5
Rec 6
RECYCLE NUMBER

Figure 6

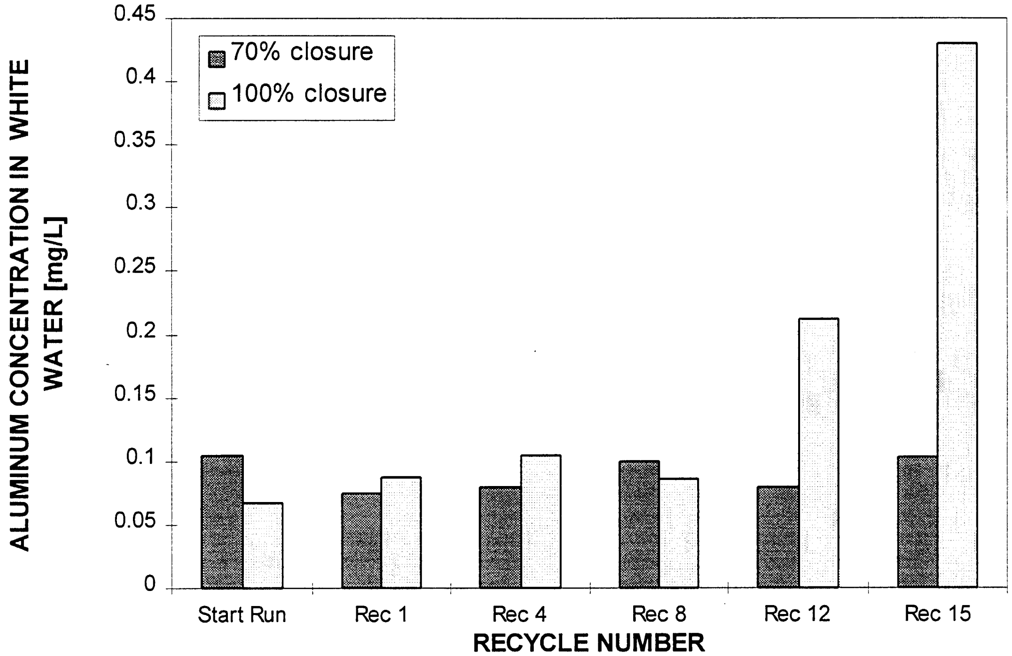

70% closure
100% closure
ALUMINUM CONCENTRATION IN WHITE WATER [mg/L]
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Start Run
Rec 1
Rec 4
Rec 8
Rec 12
Rec 15
RECYCLE NUMBER

Figure 7